(12) UK Patent Application (19) GB (11) 2 241 710 (13) A

(43) Date of A publication 11.09.1991

(21) Application No 9103362.1

(22) Date of filing 18.02.1991

(30) Priority data
(31) 9003604 (32) 16.02.1990 (33) GB

(51) INT CL⁵
C23C 14/35, H01J 37/34

(52) UK CL (Edition K)
C7F FEAB F103 F210 F230
H1D DGQ D10 D38 D8X

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(58) Field of search
UK CL (Edition K) C7F FCAS FCSE FCSL FCSM
FCSX FEAB, H1D DGQ
INT CL⁵ C23C, H01J
Online databases: WPI, CLAIMS

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(54) Magnetron sputtering of magnetic materials in which magnets are unbalanced

(57) A magnetron for sputtering of magnetic materials has a ferromagnetic core with an unbalanced arrangement of magnets providing a plasma entrapping field over the target. In an unbalanced magnetron the magnets of one polarity are not balanced by magnets of the opposite polarity of an equal total strength. The unbalanced arrangement enables the ferromagnetic target to be used without any artificial non-uniformity being introduced into the target to provide the field lines above it. In an unbalanced magnetron some lines of force tend to travel outside the target disc above its surface, in contradistinction to a balanced magnetron where the lines of force tend to travel within the target disc when it is of magnetic material, and thus are useful to effect the plasma (Fig. 4).

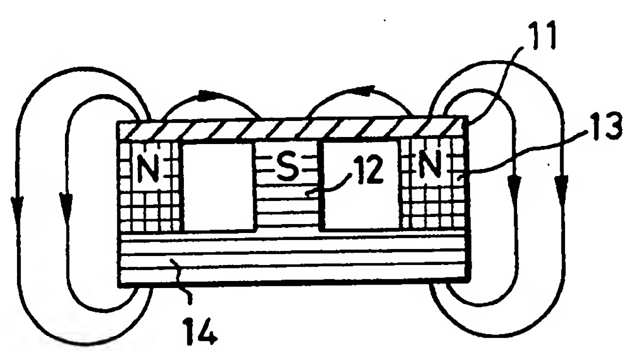

FIG.4.

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

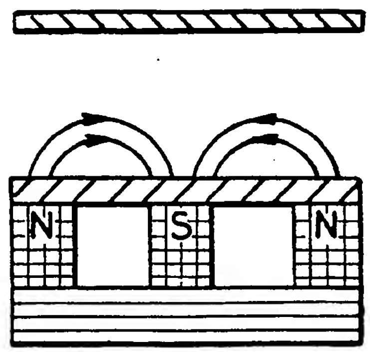

FIG.1.

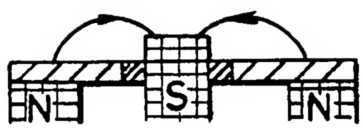

FIG.2.

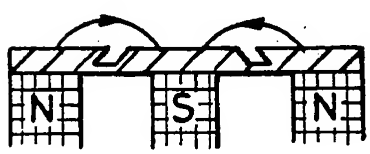

FIG.3.

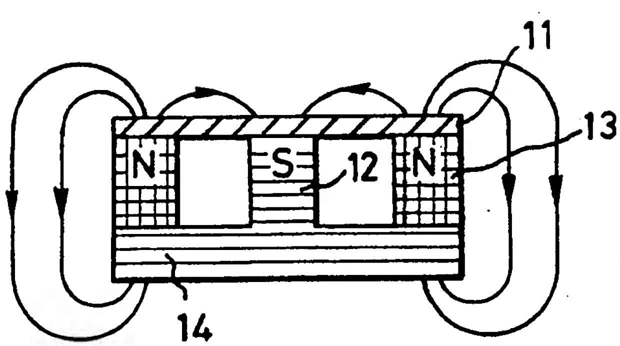

FIG.4.

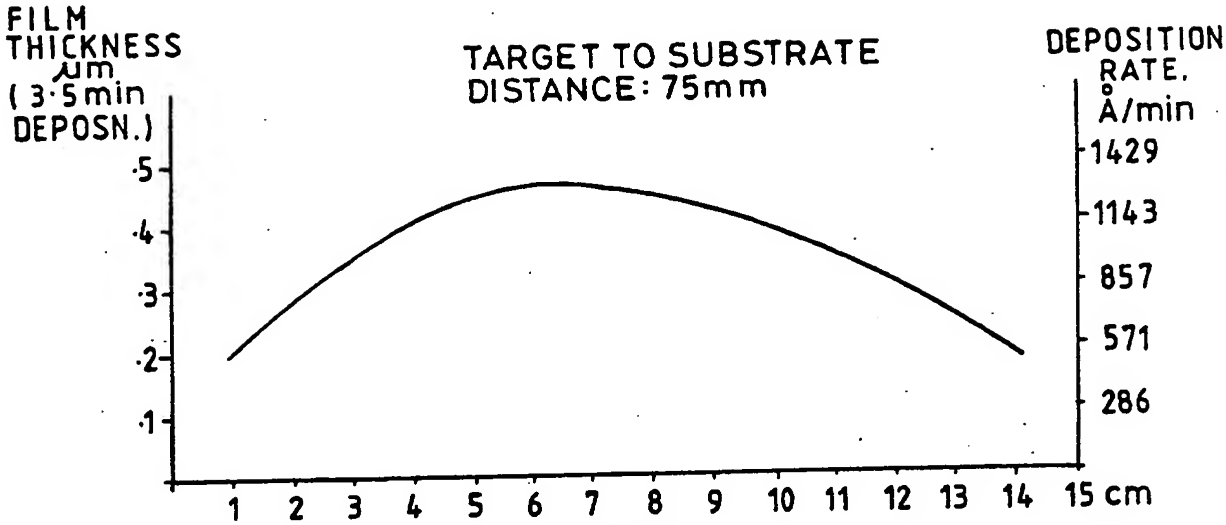

FIG.5.

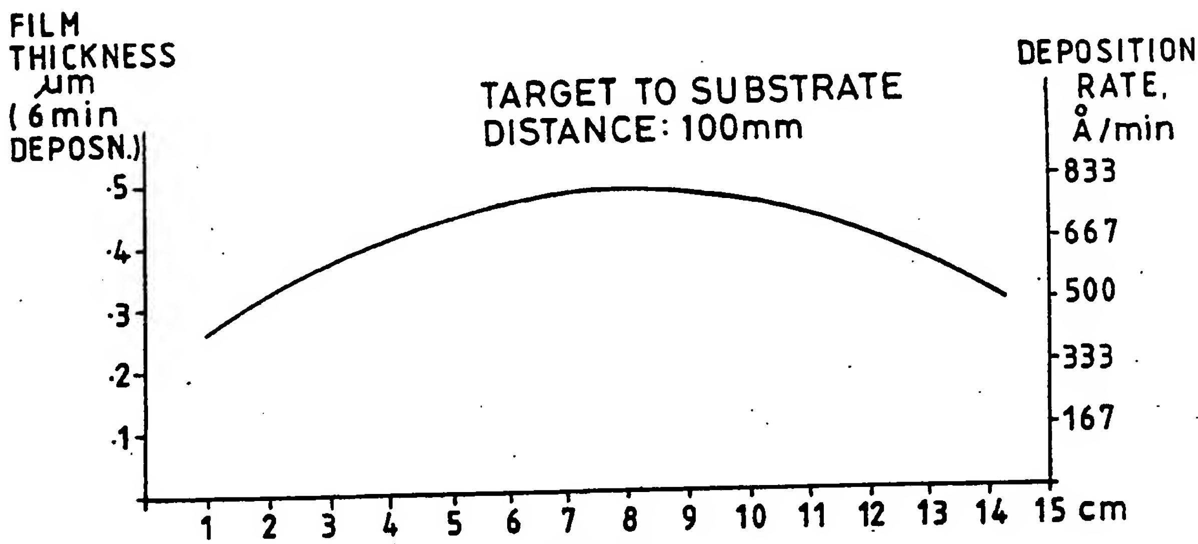

FIG.6.

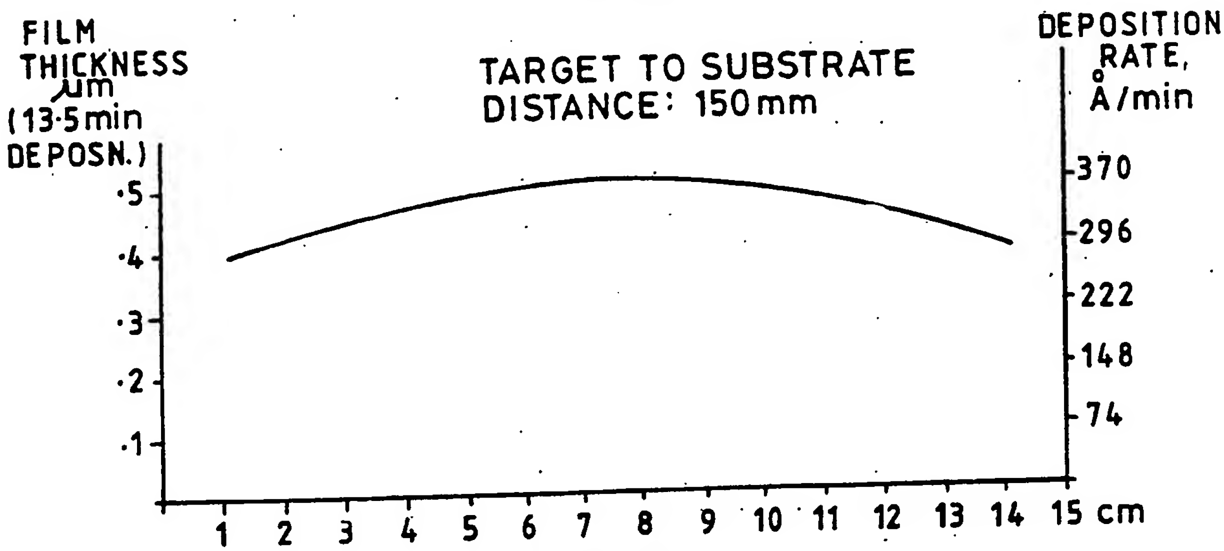

FIG.7.

MAGNETRON SPUTTERING OF MAGNETIC MATERIALS

To deposit films of a target material on to a substrate by sputtering, the target and substrate may be mounted opposite each other in a vacuum system. The target is biased negatively with respect to the anode and a gas (generally inert, such as argon) is introduced. Under the action of the electric field, the gas is ionised, positive ions, bombard the target which is sputtered on to the substrate as a film. To sustain the discharge, the gas pressure is about 10 pascals. With this diode system, deposition rates are relatively low.

To enhance the rate, the ionising electrons may be confined to near the surface of the target by a magentic field. This gives rise to an intense plasma above the target, which provides efficient sputtering at pressures of 1 to 0.1 pascals. A convenient arrangement of a magnetron sputtering system is shown in Figure 1. The target is a disc, with magnets beneath the circumference of the disc, a magnet or a ring of magnets at the centre of the disc all of one polarity and an outer ring of magnets with the opposite polarity. The magnetron is balanced when the total strength of the magnets of one polarity is equal to the total strength of the magnets of the other polarity. A magnetic field is then established above the target. However, if the target is a ferromagnetic material, the magnetic field tends to be confined within the target material and the sputtering rate is reduced to that of a diode.

Various methods have been proposed to improve the sputtering rate for magnetic materials. Instead of a disc, the target is machined as an annulus allowing the centre magnet to protrude above the target (Figure 2). A non-magnetic spacer is placed between the magnet and the annular

target to break the magnetic circuit. To avoid sputtering of the central magnet it is advisable to cover it with the same magnetic material as the target.

Another technique is to machine grooves in the target to increase the magnetic impedance. (Figure 3).

A further method is to use a thin foil target, which is magnetically saturated by the field, allowing a magnetic field to establish itself above the target.

The methods as shown in Figures 2 and 3 have the disadvantage that the target must be machined, which may prove difficult for some materials and may be wasteful. The use of thin foils limits the sputtering time before renewal and may cause difficulties as regards heating.

The object of this invention is to sputter ferromagnetic targets as rigid discs without machining. We provide a magnetron comprising a ferromagnetic target and means to generate a magnetic field above the surface of the target including magnets in an unbalanced arrangement. Whereas the strength of the magnets of the two polarities were equal in the balanced magnetron as described above, in the unbalanced magnetron according to the present invention the magnets of one polarity are not balanced by magnets of the opposite polarity of an equal total strength. Preferably the magnets of the one polarity are arranged in a ring beneath the periphery of the target, and a magnet or magnets of the opposite polarity or even just magnetic material is or are arranged at the centre of the target. This can for example be arranged by providing the central magnetic material of mild steel or soft iron, while the peripheral magnets are of permanently magnetised material such as a cobalt alloy, (eg., samarium cobalt) material. Whereas in a balanced magnetron the lines of force between the upper poles of the magnets tend to travel within the target disc when it is of magnetic material and thus do not affect the plasma to an appreciable extent, we

have found that with an unbalanced magnetron some lines of force tend to travel outside the disc above its surface and so are useful to affect the plasma. The effect is achieved without the complication of grooving or drilling the target disc.

Examples of the prior art have been described with reference to Figures 1 to 3 and an example of the invention will now be described with reference to Figures 4 to 7. In these Figures,

Figure 1 is a diametral section through a balanced magnetron of the prior art,

Figures 2 and 3 are details of two different modifications of the prior art magnetron of Figure 1,

Figure 4 is a similar section through a magnetron according to the present invention, and

Figures 5 to 7 show the relationship of film thickness and deposition rate to position on a target for different combinations of periods of deposition and target to substrate distances.

In an example of the invention shown in Figure 4, a plane steel disc 11 2mm thick and 76mm diameter acts as the ferromagnetic target above a central magnetic material core 12 of mild steel and a ring of 12 cobalt samarium magnets 13 10mm diameter and 15mm long spaced around the magnetron in a pitch circle diameter of 63.5mm diameter. The mild steel core 11 is 19mm diameter and 15mm long and with an integral mild steel lower disc 14 forms the yoke of the magnetic assembly extending to the lower ends of the outer magnets 13.

The magnetic assembly is symmetrical around the axis of the magnetron, but it is unbalanced. Whereas the magnetic lines of force in Figure 1 are confined to the region over the target because the magnets are balanced, in the unbalanced arrangement of Figure 4 there are some magnetic lines of force above the ferromagnetic steel disc 11, but also there are lines of force from the peripheral magnetic poles around the outside of the magnets to the opposite poles on the base yoke because

the total strength of the peripheral magnets 13 is greater than the strength of the magnet induced at the top of the centre ~~pin of the~~ mild steel base core. The lines of force emanating from the north poles of the ring of permanent magnets 13 to the centre of the disc 11 above the mild steel core 12 confine the electrons close to the target when the magnetron is energised, giving rise to a dense plasma above the target and hence a high sputtering rate. If the magnetic field does not extend in this way above the target, the plasma is no longer confined close to the target, resulting in a reduced sputtering rate.

In place of mild steel, the yoke and central magnet could be of soft iron. It would also be possible for the central "core" to be of permanent magnetic material, provided that its total strength was not equal in magnitude to the total of the outer ring. The disc 14 in this case would preferably be a separate piece from the central core and of non-permanent magnetic material.

It is emphasised that the dimensions quoted above are of one example only. Magnetrons of this arrangement have been made with diameters in the range 20 to 178mm. Furthermore non-circular magnetrons can be made, eg., rectangular and a typical size is, 76mm x 216mm.

CLAIMS

1. A magnetron comprising a ferromagnetic target and means to generate a magnetic field above the surface of the target including magnets in an unbalanced arrangement.

2. A magnetron as claimed in claim 1 wherein the magnets of the one polarity are arranged in a ring beneath the periphery of the target, and a magnet or magnets of the opposite polarity is or are arranged beneath the centre of the target.

3. A magnetron as claimed in claim 1 wherein the magnets of the one polarity are arranged in a ring beneath the periphery of the target, and magnetic material is arranged beneath the centre of the target.

4. A magnetron as claimed in claim 3 wherein the central magnetic material comprises mild steel.

5. A magnetron as claimed in claim 2 wherein the peripheral magnets are of permanently magnetised material.

6. A magnetron as claimed in claim 5 wherein the permanently magnetised material is a cobalt alloy.

7. A magnetron as claimed in any one of the preceding claims wherein wherein the target comprises a uniform plane disc.

8. A magnetron substantially as herein described with reference to the accompanying drawings.